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# David Taylor Research Center

Bethesda, Maryland 20084-5000

DTRC SHD-1322-01 February 1990

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Ship Hydromechanics Department

Departmental Report

## HYDRODYNAMIC TOWING EVALUATION OF THE USS SKATE (SSN-578)

by

Stephen A. McCauley
Raymond P. Para



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DTRC SHD-1322-01 HYDRODYNAMIC TOWING EVALUATION OF THE USS SKATE (SSN-578)



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An experimental evaluation was conducted to investigate the surface towing characteristics of the USS SKATE (SSN-578). A 1/14.198-scale model was towed in the David Taylor Research Center (DTRC) deep-water towing basin using a single towpoint and several sternplane configurations. The results indicate that the SSN-578 can be satisfactorily towed with an additional 50% ~~percent~~ sternplane area aft and the sternplane set at 25 deg trailing edge up. Keywords: Nuclear powered submarines; Submarine models; Towed bodies; Scale models; Hydrodynamic stability; Hydrodynamic control surfaces performance. (EDC)


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## ABSTRACT

An experimental evaluation was conducted to investigate the surface towing characteristics of the USS SKATE (SSN-578). A 1/14.198-scale model was towed in the David Taylor Research Center deep-water towing basin using a single towpoint and several sternplane configurations. The results indicated that the SSN-578 can be satisfactorily towed with an additional 50 percent sternplane area aft and the sternplane set at 25 deg trailing edge up.


## ADMINISTRATIVE INFORMATION


This project was sponsored by the Pearl Harbor Naval Shipyard through Work Request WR21512 of 26 November 1986 with the Naval Sea Systems Command, (NAVSEA) Code 55W31, the technical point of contact. This work was performed by the David Taylor Research Center under Work Unit 1-1541-113.


## INTRODUCTION

At the request of the Naval Sea Systems Command, the David Taylor Research Center (DTRC) undertook a program to investigate the surface towing characteristics of the SSN-578 submarine. Submarines under surface tow often display undesirable tow characteristics such as yawing and extreme kiting to one side. The classic description of a stable tow has the tow positioned directly astern of the tug. As the tow yaws and moves further outboard from a centerline position behind the tug, the situation can become difficult, if not unacceptable. Several basin evaluations have looked at stabilizing efforts for a submarine under tow.[1,2]

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[1]Para, R. P., "A Stability Investigation of Various Towing Configurations and Stabilizing Devices for a Modified SSBN-598 Class Submarine," DTNSRDC Report SPD-0202-06 (Mar 1982).

[2]Para, R. P., "Hydrodynamic Towing Evaluation of the USS DOLPHIN (AGSS-555)," DTNSRDC Report SPD-0906-01 (Jul 1979).

The purpose of this effort was to determine the best towing configuration for the submarine and to present the results of these evaluations. This report describes the model and the experimental procedure. Towline tension and towline angles are presented as a function of speed for various sternplane configurations.

## MODEL DESCRIPTION

An 18.85 ft (5.75 m) long free-flooding mahogany model of the USS SKATE was used for the basin evaluation. The model has a linear scale ratio of 14.198. The model is shown in Fig. 1 with its ballast conditions listed in Table 1. The sail was not fitted to the model since during a surface tow it is completely out of the water and therefore does not have any hydrodynamic effect on the stability of the submarine. A single towpoint was used with a full scale location of 23.83 ft (7.20 m) above the baseline (ABL) and on the forward perpendicular. The model towpoint is shown in Fig 2. The screw eye shown on the top of the model was only used for handling purposes.

## PROCEDURE

The model was statically trimmed for surface towing by ballasting to waterline 1 with a trim of 4.66 ft (1.42 m) down by the stern and waterline 2 with a trim of 4.01 ft (1.22 m) down by the stern. Roll incline tests were then conducted to obtain the two required metacentric heights (GM) of 1.06 ft (0.32 m) and 0.85 ft (0.25 m). The tow tests were conducted in the deep-water basin at DTRC. The basin is 22 ft (6.7 m) deep, 51 ft (15.5 m) wide, and has an approximate run length of 800 ft (243.8 m). The model was towed at equivalent full-scale speeds of 4, 7 and 10 kn (2.06, 3.6, and 5.14 m/s). The length of the nylon towline used was 16 ft (4.88 m) and had a diameter of

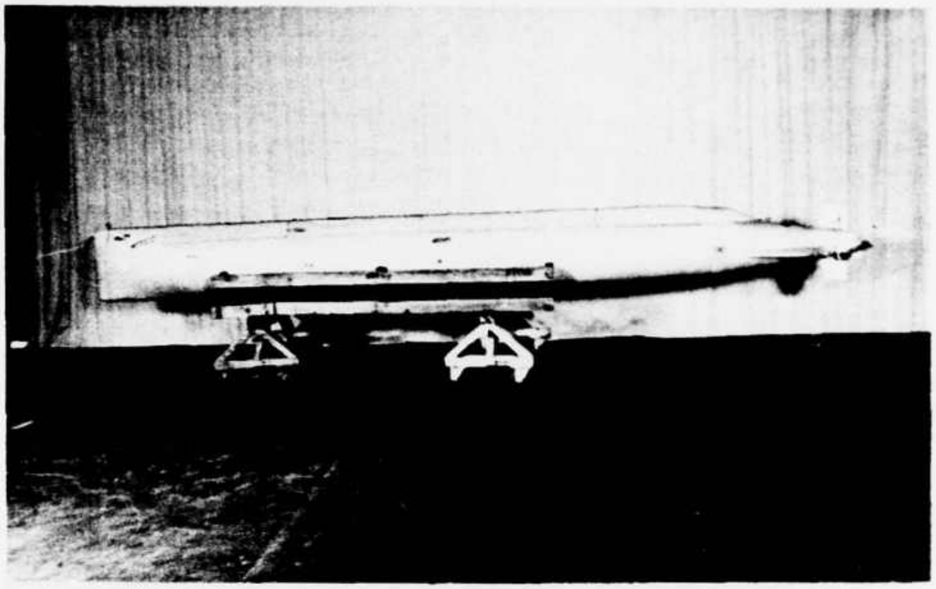

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Fig. 1. Model of the USS SKATE (SSN-578).

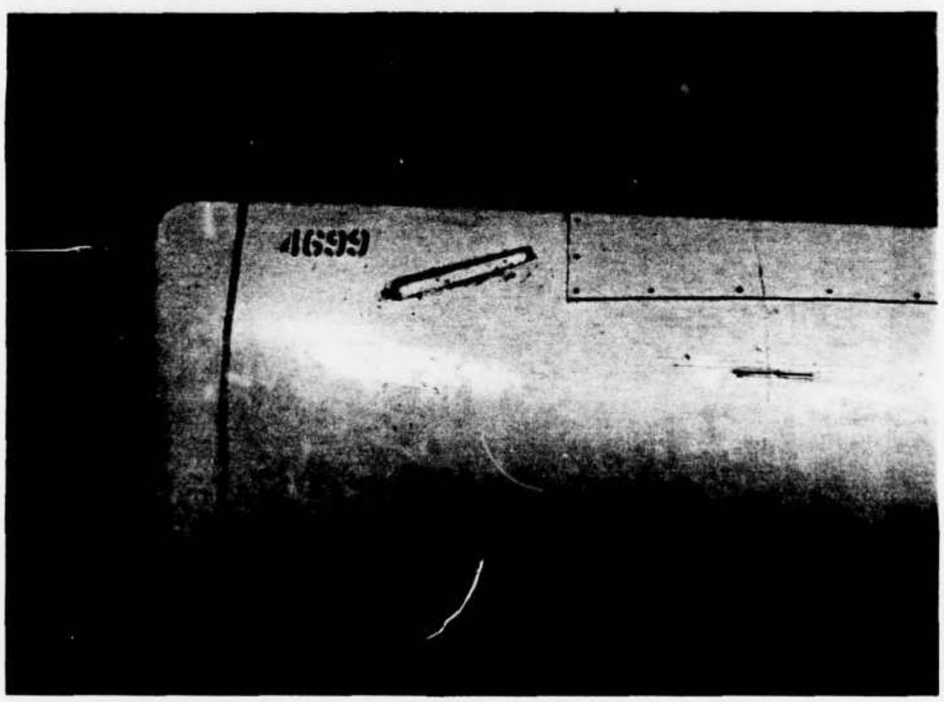


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Fig. 2. Towpoint location used in the SSN-578 evaluation.

Table 1. Ballast conditions for the SSN 578 submarine model.

| Ship Characteristics | Full Scale | Model |
|---|---|---|
| Displacement | 2,215 Tons (SW) (2,250,948 Kg) | 1,686 lbs (FW) (765 Kg) |
| Mean Draft | 17.75 ft (5.4 m) | 15 in. (0.38 m) |
| **WATERLINE 1** | | |
| GM Required | 1.06 ft (0.32 m) | 0.89 in. (0.023 m) |
| Draft (FWD) | 16.3 ft (4.97 m) | 13.78 in. (0.35 m) |
| Draft (AFT) | 19.44 ft (5.93 m) | 16.43 in. (0.42 m) |
| **WATERLINE 2** | | |
| GM Required | 0.85 ft (0.26 m) | 0.72 in. (0.018 m) |
| Draft (FWD) | 16.5 ft (5.03 m) | 13.95 in. (0.35 m) |
| Draft (AFT) | 19.2 ft (5.85 m) | 16.23 in. (0.41 m) |

1/8 in. (0.003 m). Only one towline length was used, since earlier basin tests have shown that various towline lengths[3] do not affect the towing behavior of the model.

Once the carriage reached the desired speed, the model was displaced to one side of the tow carriage's centerline and then allowed to seek its equilibrium position. The towing stability was evaluated at sternplane settings of 0, 10, and 25 deg trailing edge up (TEU). The following four sternplane configurations were evaluated:

1. Additional 50 percent sternplane area aft (Fig. 3),
2. Additional 50 percent sternplane area outboard (Fig. 4),
3. Vertical end plates on the sternplane tips (Fig. 5), and
4. Sternplanes with no extensions (Fig. 6).

## INSTRUMENTATION

The instrumentation located at the gimbal towpoint consisted of:

1. An angle potentiometer to measure the horizontal towline angle, defined as the towline angle relative to the direction of tow, projected onto a horizontal plane. The potentiometer has a range of 60 deg port and starboard with a system accuracy of $\pm$ 0.5 deg.

2. A 50 lb (222 N) capacity ring gage dynamometer to provide measurements of towing tension with a system accuracy of $\pm$ 0.25 lb (1 N). The full scale accuracy translates to $\pm$ 735 lb (3270 N).

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[3]Mirabella, J. V., "Investigation of Techniques for Submarine Towing," DTNSRDC Report 432-H-01 (Jun 1971).

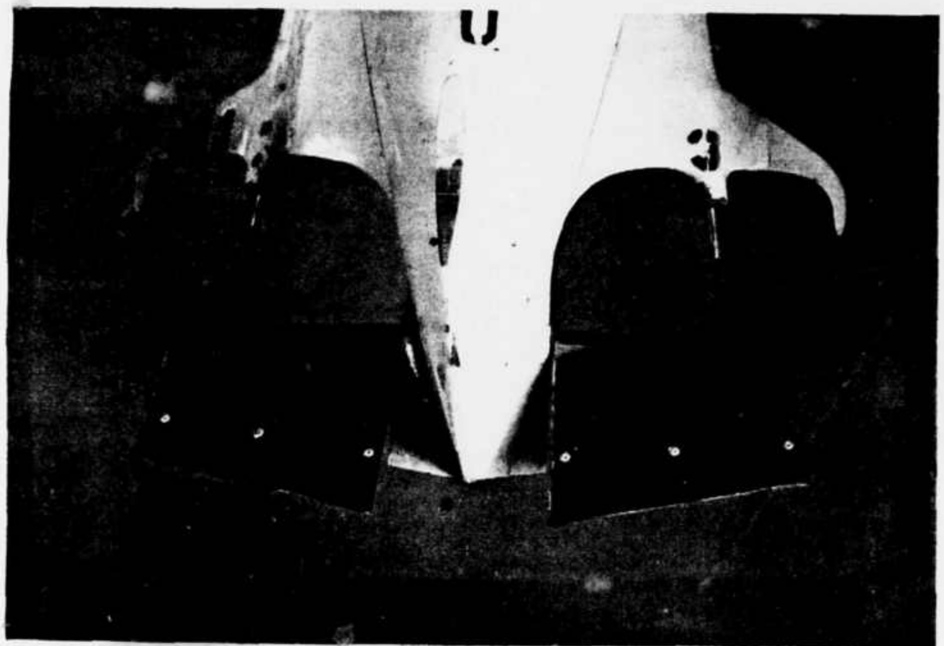

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Fig. 3. SSN-578 submarine model with sternplane extensions aft.

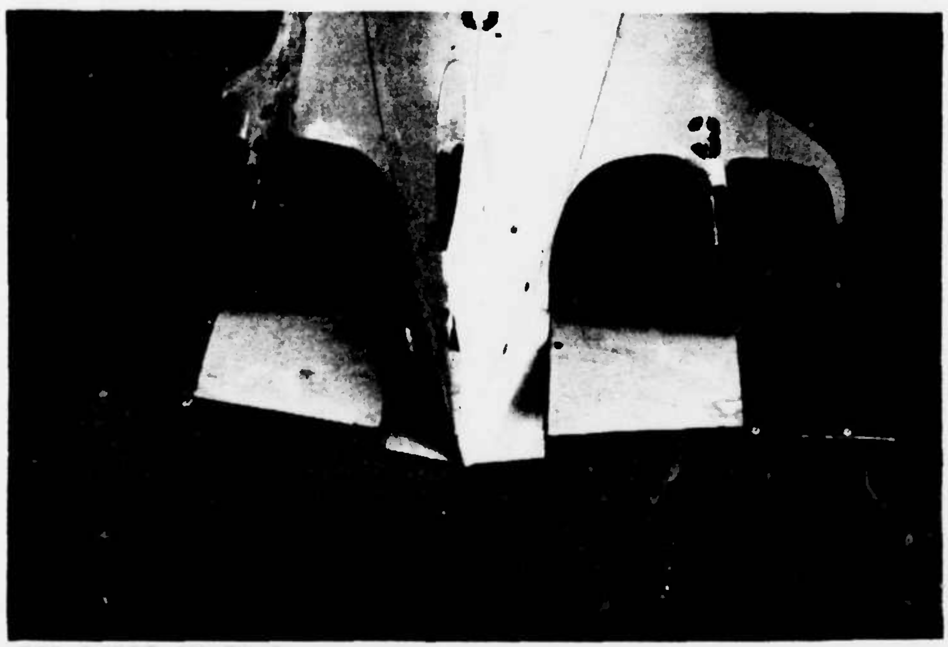

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Fig. 4. SSN-578 submarine model with sternplane entensions outboard.

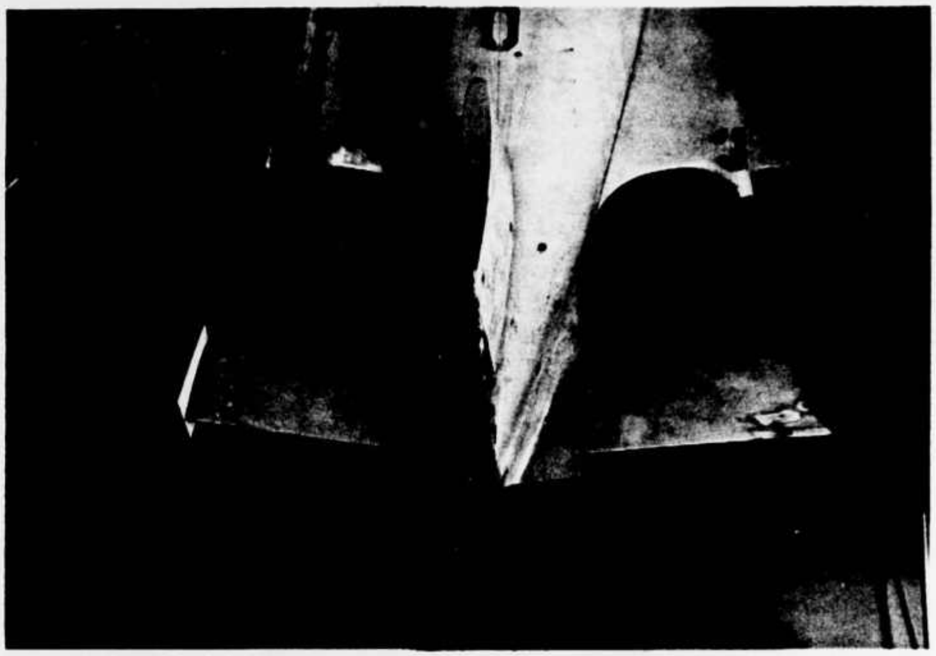

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Fig. 5. SSN-578 submarine model with vertical end plates on the sternplane tips.

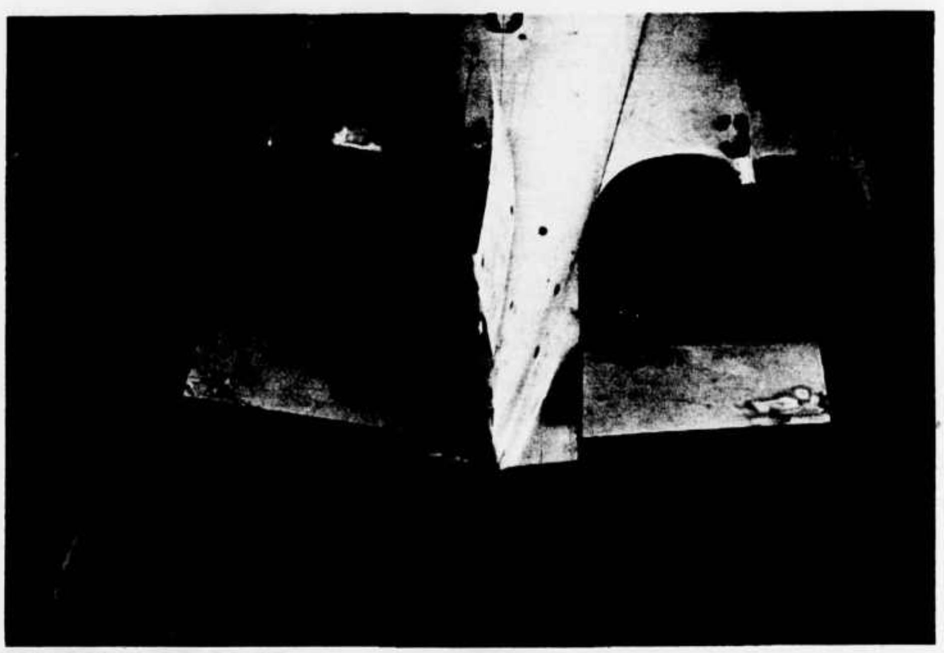

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Fig. 6. SSN-578 submarine model without sternplane extensions.

Additional instrumentation consisted of a magnetic pickup on the towing carriage to provide measurements of speed with a model accuracy of $\pm$ 0.01 kn and a full-scale accuracy of $\pm$ 0.04 kn. For all measurements, data readout was provided by an eight-channel stripchart recorder and an HP9836 computer.

## RESULTS AND DISCUSSION

The test results are presented as full-scale values. The towline tension was scaled by:

$$\frac{\rho_{sea}}{\rho_{fresh}} \lambda^3$$

where $\rho_{sea}$ is the density of sea water at 59 deg F.,

$\rho_{fresh}$ is the density of the basin water at 68 deg F., and

$\lambda$ is the linear scale ratio.

For all conditions and speeds when the model was deflected to port or starboard, it did not exhibit a preference for either side of the centerline. The horizontal towline angle measurements taken after the model had reached an equilibrium condition are presented in Table 2 for various speeds, sternplane angles, sternplane extensions, and a GM of 1.06 ft (0.32 m). The horizontal towline angle and towline tension are presented for various speeds, for a GM of 0.85 ft (0.26 m) with extensions aft and a sternplane angle of 25 deg TEU in Table 3.

The SSN-578 model without extensions exhibited undesirably large horizontal towline angles at speeds of 4, 7, and 10 kn (2.06, 3.6, and 5.14 m/s). With the sternplane angle set to 25 deg TEU, the horizontal towline angle was reduced with the addition of either sternplane extensions aft, extensions outboard, or vertical end plates for all speeds tested.

Table 2. Horizontal towline angles for various speeds, sternplane angles, and sternplane configurations at a GM of 1.06 ft (0.32 m).

| Carriage Speed Kn (m/s) | 1. Extensions Aft | | 2. Extensions Outboard | | 3. Vertical (End Plates) | | 4. No Extensions | |
|---|---|---|---|---|---|---|---|---|
| Sternplane angle (deg) TEU | 10 | 25 | 10 | 25 | 10 | 25 | 0 | 5 |
| | Horizontal Towline Angles (deg) | | | | | | | |
| 4 (2.06) | 46±12 | 4.5 | 42 | 23 | >50 | 12 | Unsteady ±12 | 20±10 |
| 7 (3.6) | 10 | 2 | 19 | 10 | 22 | 5 | 40 | Unstable 0±10 |
| 10 (5.14) | 12 | 13 | 13 | 2±6 | 10 | 14 | Unsteady 40±20 | Unstable 0 |

Table 3. Horizontal towline angle and towline tension for various speeds at a GM of 0.85 ft (0.26 m) extension aft, and a sternplane angle of 25 deg TEU.

| Speed Kn (m/sec) | Angle deg | Tension lbs (N) |
|---|---|---|
| 4 (2.06) | 14 | 7,100 (31,400) |
| 7 (3.6) | 7 | 13,800 (61,400) |
| 10 (5.14) | 3 | 27,900 (124,200) |

For all three sternplane configurations with extensions and a 10 deg sternpane angle, an acceptable horizontal towline angle range of ± 15 deg was not acheived until the model reached a speed of 7 kn (3.6 m/s). When the sternplane angle was increased to 25 deg, the horizontal towline angle damped within the acceptable range for all configurations except extensions outboard at 4 kn (2.06 m/s). Horizontal towline angle as a function of time for a sternplane angle of 25 deg TEU, for all configurations, is presented in Figs. 7 and 8. The effect of GM on the horizontal towline angle is shown as a function of elapsed time in Figs. 9 and 10.

Towline tension is presented as a function of speed, sternplane angle and sternplane configuration in Table 4. The effect of sternplane angle and sternplane configuration on the towline tension is seen to be minimal.

## CONCLUSIONS

The following conclusions are reached based on the results of this towing evaluation:

1. The SSN-578 with no extensions and a zero deg sternplane setting creates an undesirable tow at all speeds.

2. Adding extensions to the sternplanes improved the submarine's towing performance with the best results obtained with the sternplane extensions aft.

3. The sternplane angle should be set to an angle of 25 deg trailing edge up.

4. The GM should be between 0.85 ft (0.26 m) and 1.06 ft (0.32 m) full-scale.

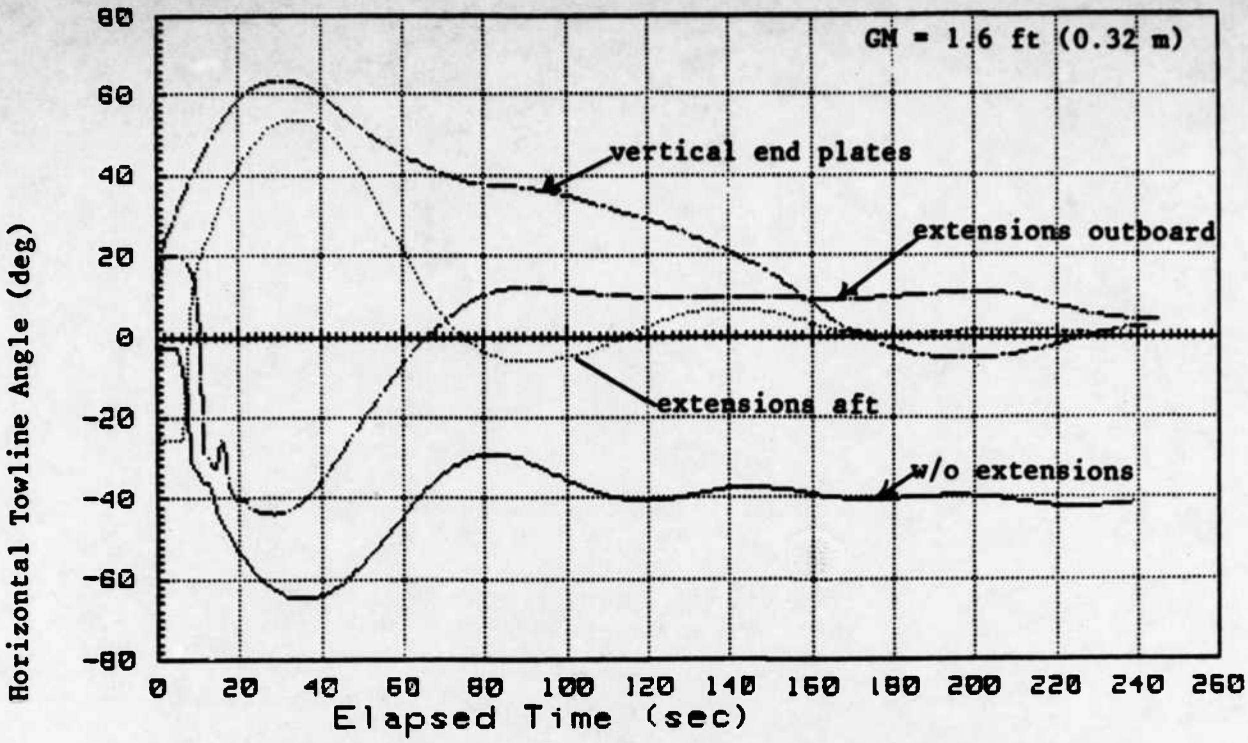


Fig. 7. Horizontal towline angle as a function of elasped time for 4 sternplane configurations at 7 kn (3.6 m/s)

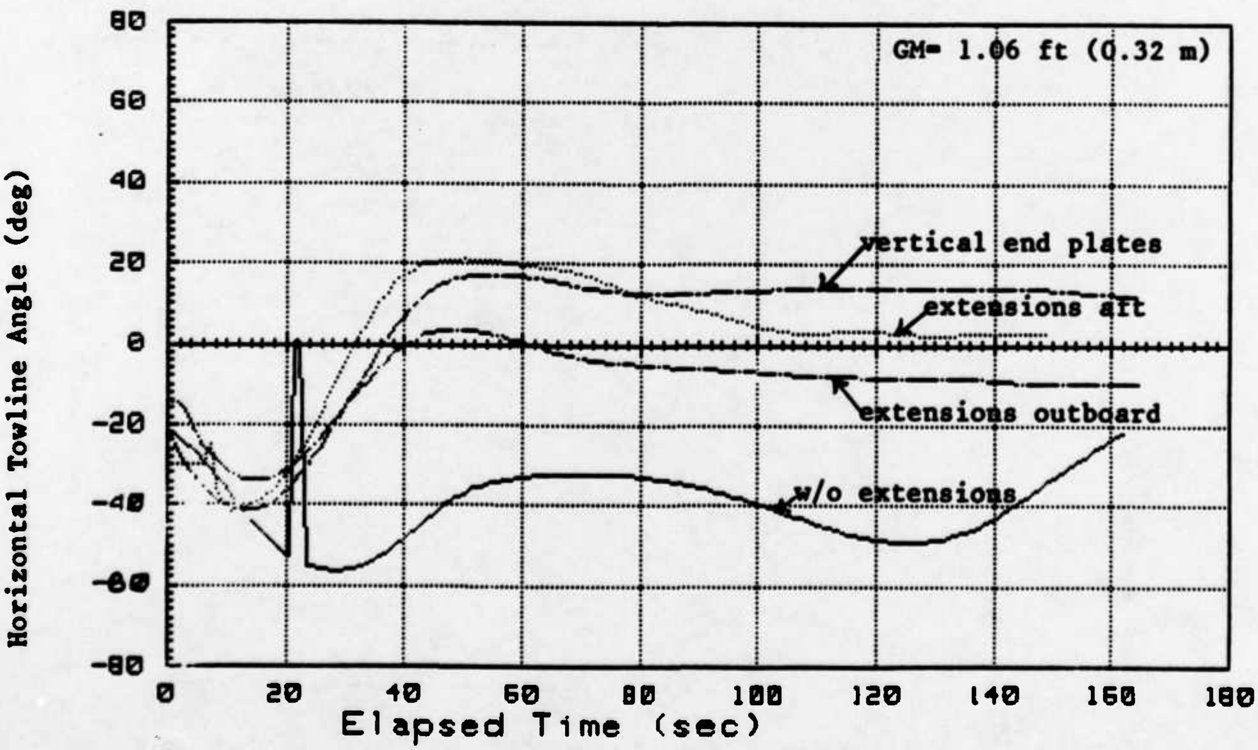


Fig. 8. Horizontal towline angle as a function of elasped time for 4 sternplane configurations at 10 kn (5.14 m/s).

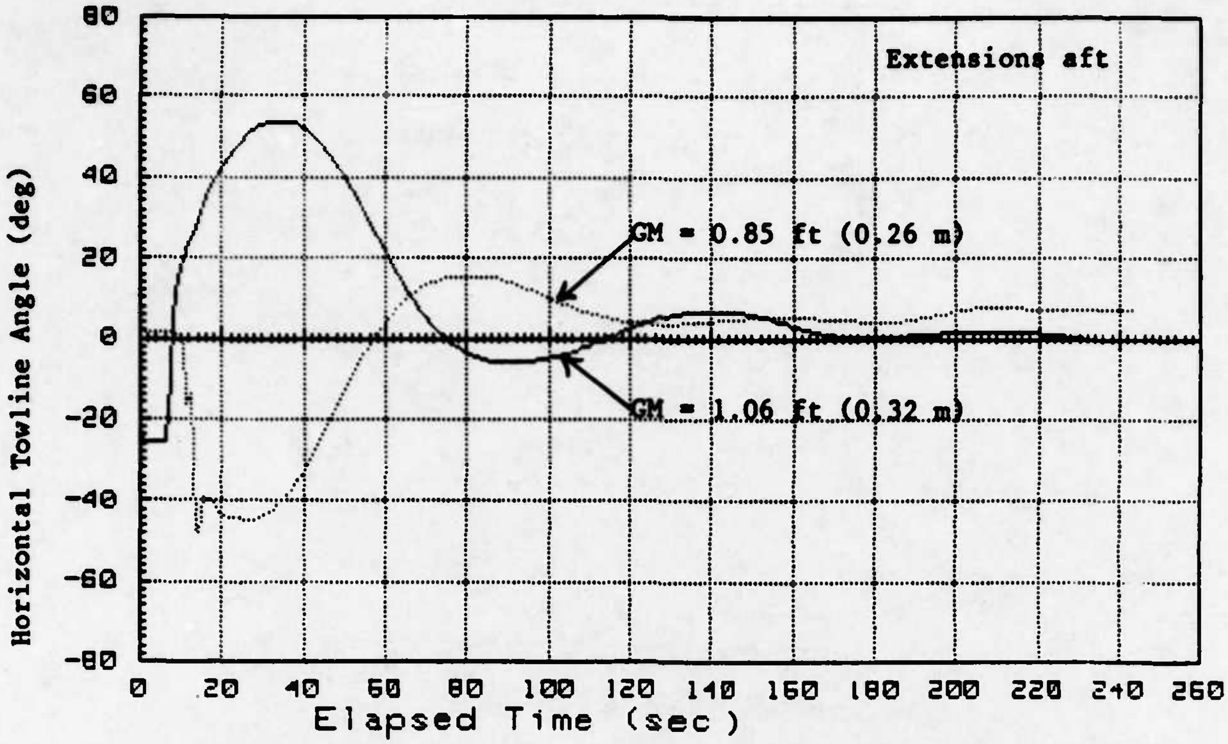


Fig. 9. Horizontal towline angle as a function of elasped time for 2 GM values at 7 kn (3.6 m/s).

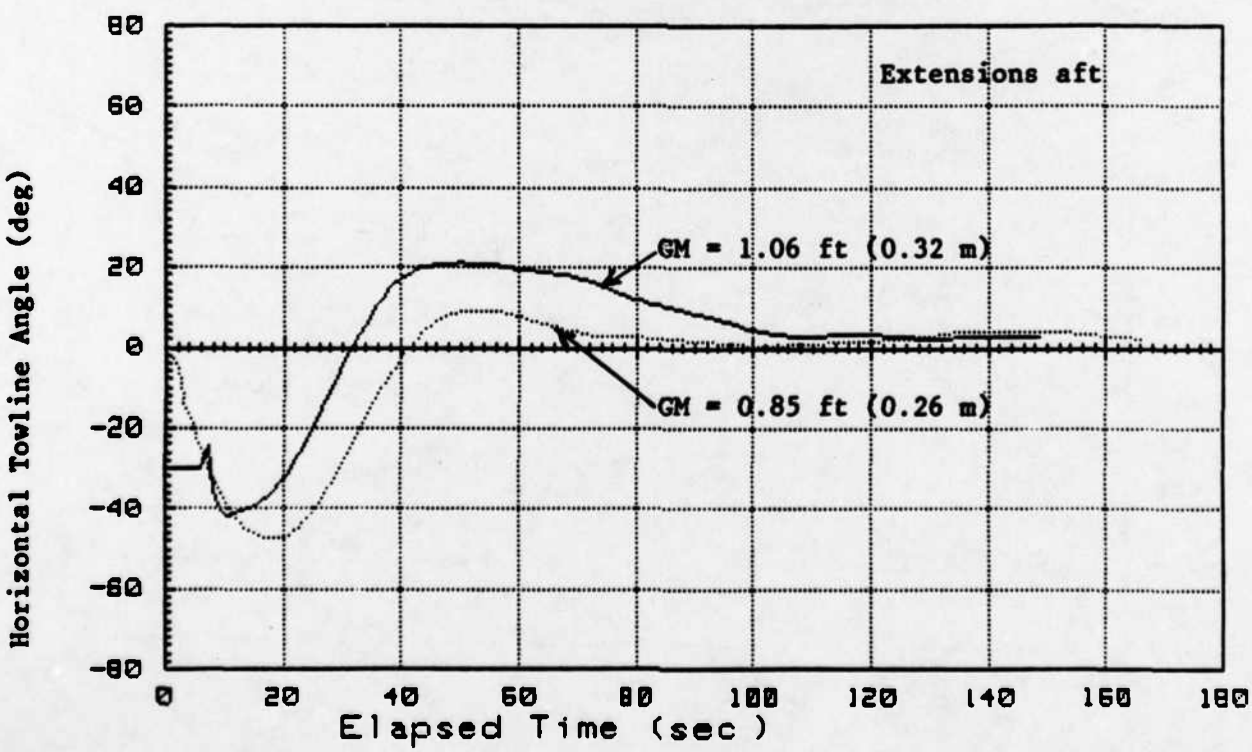


Fig. 10. Horizontal towline angle as a function of elasped time for 2 GM values at 10 kn (5.14 m/s).

**Table 4. Towline tension for various speeds, sternplane angles, and sternplane configurations at a GM of 1.06 ft (0.32 m).**

| Speed (Kts) | Extensions Aft lb(N) | | Extensions Outboard lb (N) | | Vertical End Plates lb (N) | | No Extension lb (N) | |
|---|---|---|---|---|---|---|---|---|
| | 10° | 25° | 10° | 25° | 10° | 25° | 0° | 25° |
| 4 | 6,800 (30,000) | 4,400 (19,600) | 7,000 (31,400) | 7,300 (32,700) | 8,800 (39,200) | 12,300 (54,900) | 5,000 (22,200) | 6,500 (28,700) |
| 7 | 12,600 (56,200) | 12,300 (54,900) | 11,800 (52,300) | 15,300 (67,900) | 11,800 (52,300) | 12,300 (54,900) | 14,700 (65,400) | 11,800 (52,300) |
| 10 | 25,900 (115,000) | 27,900 (124,200) | 23,500 (104,600) | 30,900 (137,300) | 22,900 (102,000) | 27,000 (120,300) | 30,600 (135,900) | 26,500 (117,600) |